

# FINAL REPORT

## FOR NAG 2-1324: COMPUTATION OF HIGH SPEED JET NOISE

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The objective of this work was to use direct numerical simulation techniques to study the physics of noise generation by a high-speed turbulent jet. A Mach 0.9, Reynolds number 3,600 jet was selected because of available experimental data.<sup>1</sup> New numerical methods for generating disturbances at the nozzle<sup>2</sup> and computing far-field sound<sup>3</sup> were developed and reported in the course of this work. Over 25 million mesh points were used in the simulations which ran for over 50,000 timesteps and required over 50,000 processor hours on state-of-the-art parallel computer systems to complete. Figures 1-4 show a visualization of the jet and sound field, a comparison of the mean flow development with the experiment, a directivity comparison with the experiment, and time spectrum comparison with the experiment. Agreement is seen to be excellent. These are fully document in the attached references.

Full details of the work, detailed achievements and conclusions are discussed appendix A-C which are copies of publications that resulted from this work. We have studied noise mechanisms in supersonic jets,<sup>4</sup> the refraction of sound by turbulence in subsonic jets,<sup>5</sup> and noise sources in conjunction with a DNS of a Mach 0.9 jet.<sup>2</sup>

### References

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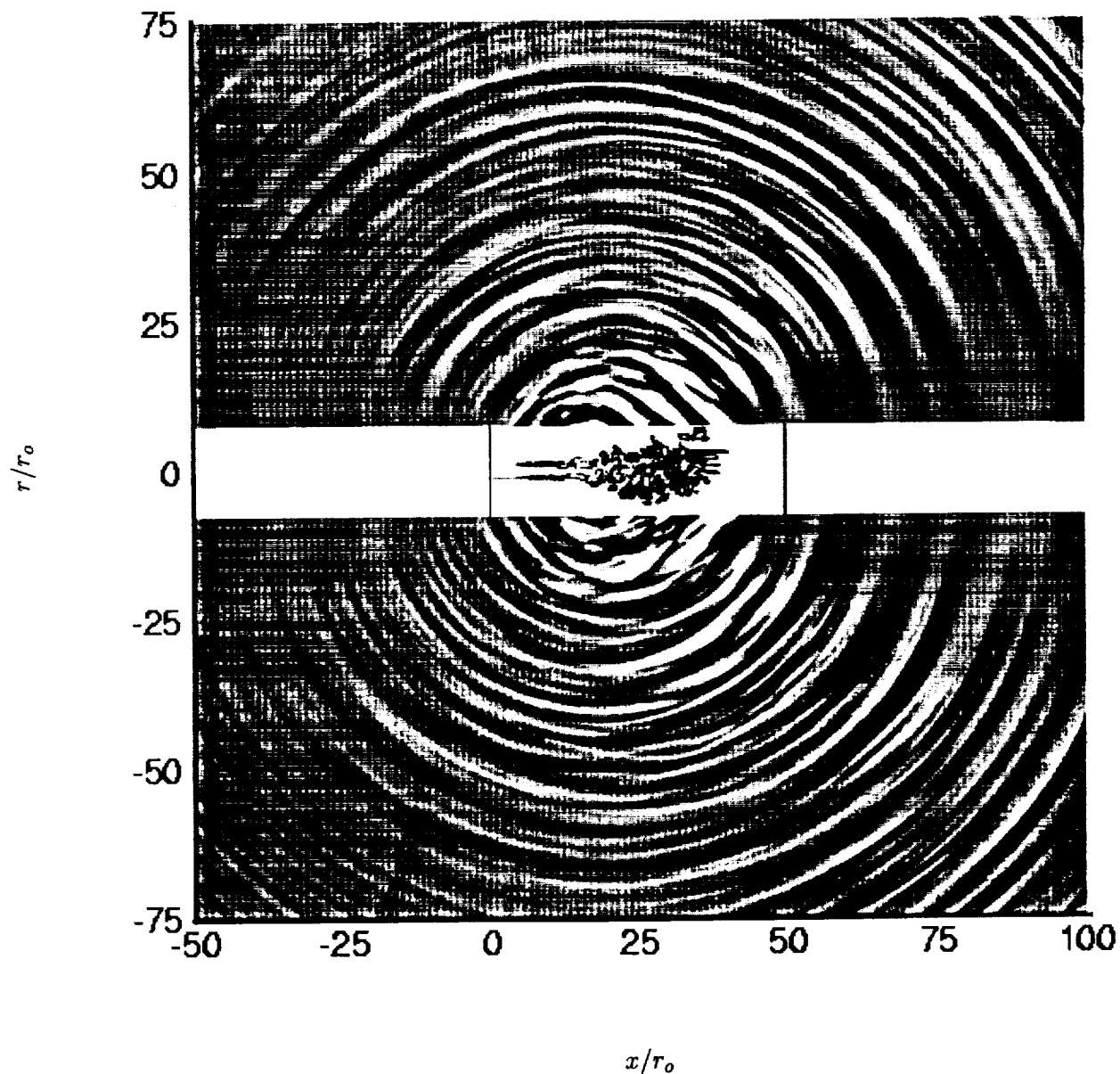


Figure 1: Visualization of the far-field sound: Black is  $\Theta = \nabla \cdot \mathbf{u} < -0.0005a_0/r_0$  and white is  $\Theta > 0.0005a_0/r_0$ . The grey scale vary continuously between these extrema. The jet is visualized with contours of vorticity magnitude as in figure. The axial boundaries of the numerical domain (including the boundary zone) are demarked by the vertical lines. Only radiating modes are shown (see appendix). Note that because of the geometry of the computational domain there is a blockage effect that decreases the sound near the axis in both the upstream and downstream directions. Some degree of blockage is unavoidable when computing the sound upstream and downstream of the flow computation. Geometrical reasoning suggests that sound radiating at less than  $\alpha \approx 20^\circ$  may not be accurate.

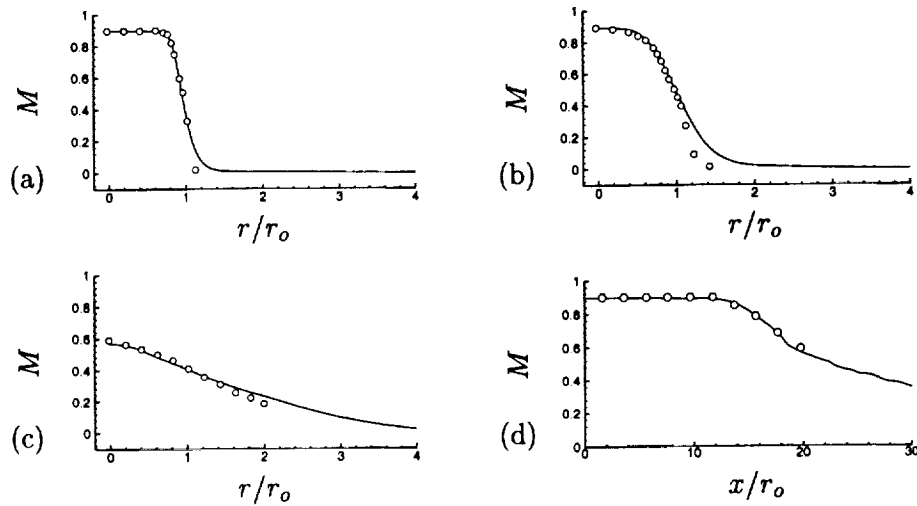


Figure 2: Mach number profiles from:  $\circ$  Stromberg *et al.*,<sup>1</sup> — present simulation. (a)  $x/r_o = 2$ ; (b)  $x/r_o = 10$ ; (c)  $x/r_o = 20$ ; (d) jet axis ( $r = 0$ ). The discrepancies at the outer edges of the jets are believed to be due and experimental error associated with using a Pitot probe in a region of small mean flow.

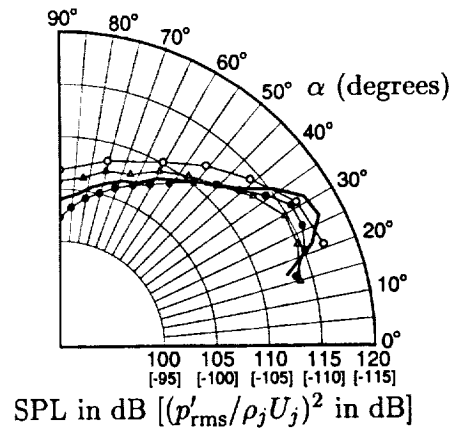


Figure 3: Overall sound pressure level (and acoustic intensity in brackets) directivity on an arc at  $60r_o$  from the nozzle and with  $\alpha$  measured from the jet axis: —  $Re = 3600$  present study,  $\bullet$   $Re = 3600$  Stromberg *et al.*<sup>1</sup> experimental data,  $\circ$   $Re = 2 \times 10^5$  Mollo-Christensen *et al.*<sup>6</sup> experimental data,  $\triangle$   $Re = 6 \times 10^5$  Lush<sup>7</sup> experimental data (adjusted by 12 decibels from 240 jet radii to 60).

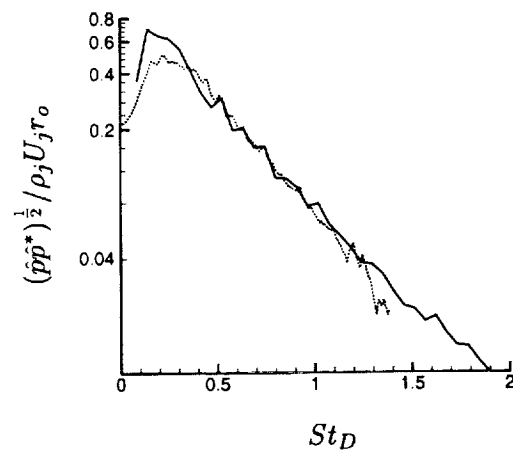


Figure 4: Far-field pressure spectrum at  $\alpha = 30$ : — present simulation; ..... measurement of Stromberg *et al.*<sup>1</sup>